IB · DP · Physics

3 hours | 16 questions

Structured Questions

6.2 Newton's Law of Gravitation

6.2.1 Newton's Law of Gravitation / 6.2.2 Circular Orbits / 6.2.3 Gravitational Field Strength

Easy (5 questions)	/59
Medium (5 questions)	/51
Hard (6 questions)	/63
Total Marks	**/173**

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Easy Questions

1 (a) State Newton's Law of Gravitation.

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(2 marks)

(b) Newton's Law of Gravitation can also be written in equation form:

$$F = G\frac{Mm}{r^2}$$

Match the terms in the equation with the correct definition and unit:

Term
F
G
M and m
r

Definition
Gravitational constant
Mass
Force
Radius

Unit
kg
N
m
N m^2 kg^{-2}

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(4 marks)

(c) Newton's Law of Gravitation applies to point masses. Although planets are not point masses, the law also applies to planets orbiting the sun.

State why Newton's Law of Gravitation can apply to planets.

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(1 mark)

(d) The mass of the Earth is 6.0×10^{24} kg. A satellite of mass 5000 kg is orbiting at a height of 8500 km above the centre of the Earth.

Calculate the gravitational force between the Earth and the satellite.

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(4 marks)

2 (a) The circular motion of a moon in orbit around a planet can be described by:

$$v = \sqrt{\frac{GM}{r}}$$

Define each of the terms in the equation above and give the unit:

(i) *v*

[1]

(ii) *G*

[1]

(iii) *M*

[1]

(iv) *r*

[1]

(4 marks)

(b) The moon Europa orbits the planet Jupiter at a distance of 670 900 km. The mass of Jupiter is 1.898×10^{27} kg.

Calculate the linear velocity of Europa.

(3 marks)

(c) The mass of Europa is 4.8×10^{22} kg.

Calculate the gravitational force between Jupiter and Europa.

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(2 marks)

(d) A second, hypothetical planet orbits Jupiter at a radius twice that of Europa, with the same mass. The gravitational force between two bodies is based on a $\frac{1}{r^2}$ rule.

Determine the force between Jupiter and the second planet as a fraction of the the force between Europa and Jupiter.

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(2 marks)

3 (a) Complete the definition of Kepler's third law using words or phrases from the selection below:

For planets or satellites in a ___________ about the same central body, the ___________ of the time period is ___________ to the ___________of the radius of the orbit.

circular orbit   linear velocity   square   cube   time

length   mass   proportional

(4 marks)

(b) Kepler's third law can also be represented by the equation:

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

Define each of the terms in the equation above and give the unit:

(i) *T* [1]

(ii) *G* [1]

(iii) *M* [1]

(iv) *r* [1]

(4 marks)

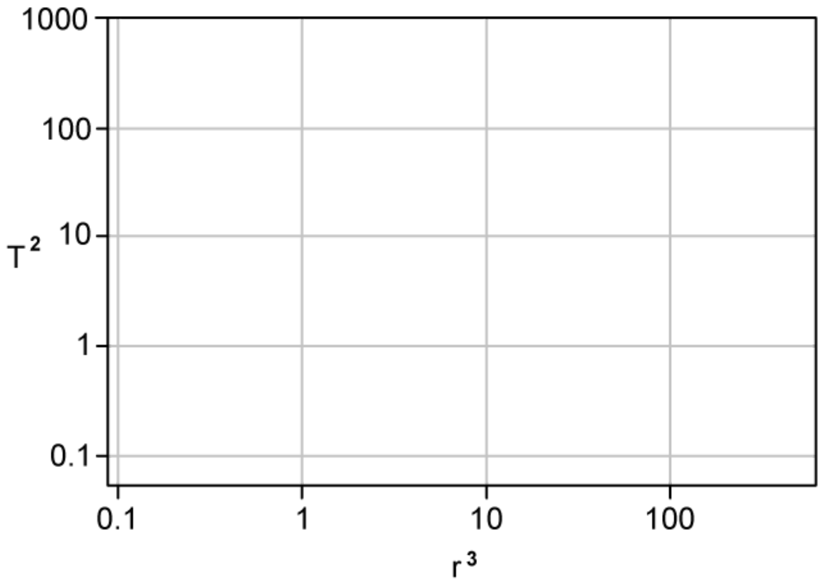
(c) Venus has an orbital period, T of 0.61 years and its orbital radius, r is 0.72 AU from the Sun.

Using these numbers, show that Kepler's Third Law, $T^2 \propto r^3$ is true for Venus. No unit conversions are necessary.

(3 marks)

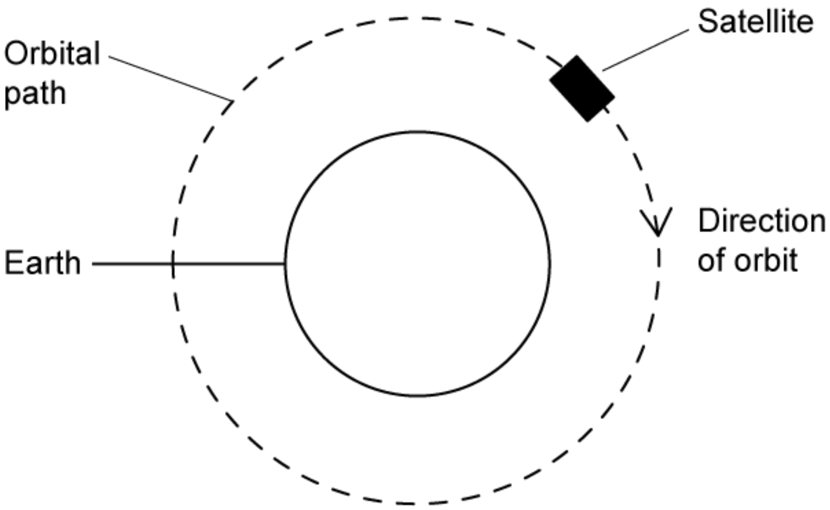
(d) Kepler's Third Law $T^2 \propto r^3$ can be represented graphically on log paper.

On the axes below, sketch a graph of $T^2 \propto r^3$ for our solar system, marking on the position of the Earth.



(3 marks)

4 (a) A satellite orbits the Earth in a clockwise direction.



Show on the diagram:

(i) The centripetal force acting on the satellite when it is in orbit, *F*.

[2]

(ii) The linear velocity of the satellite when it is in orbit, *v*.

[2]

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(4 marks)

(b) State the name of the force which provides the centripetal force required to keep the satellite orbiting in a circular path.

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(1 mark)

(c) The satellite has a mass of 7000 kg is in geostationary orbit and is constantly fixed above the same point on the Earth's surface. The radius of the geostationary orbit is 42 000 km. The Earth has a mass of 6.0×10^{24} kg.

Calculate the force required to keep the satellite in this orbit.

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(3 marks)

(d) All satellites in geostationary orbit are found at the same distance from the centre of the Earth, and are travelling at the same speed.

The equation linking speed of a satellite *v* and it's orbital radius, *r* is:

$$v^2 = \frac{GM}{r}$$

where *G* is the gravitational constant and *M* is the mass of the Earth.

Discuss why the speed is the same for every satellite in geostationary orbit, including the relevance of the satellite's mass.

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(2 marks)

5 (a) Define the following terms:

(i) Gravitational field

[2]

(ii) Gravitational field strength

[2]

(4 marks)

(b) Gravitational field strength can be written in equation form as:

$$g = \frac{F}{m}$$

Define each of the terms in the equation above and give the unit:

(i) g

[1]

(ii) F

[1]

(iii) m

[1]

(3 marks)

(c) An astronaut of mass 80 kg stands on the Moon which has a gravitational field strength of 1.6 N kg^{-1}.

Calculate the weight of the astronaut on the Moon.

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(3 marks)

(d) The mass of the Earth is 5.972×10^{24} kg and sea level on the surface of the Earth is 6371 km.

Show that the gravitational field strength, *g*, is about 9.86 N kg^{-1} at sea level.

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(3 marks)

Medium Questions

1 (a) The distance from the Earth to the Sun is 1.5×10^{11} m. The mass of the Earth is 6×10^{24} kg and the mass of the Sun is 3.3×10^{5} times the mass of the Earth.

Estimate the gravitational force between the Sun and the Earth.

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(2 marks)

(b) Mars is 1.5 times further away from the Sun than the Earth and is 10 times lighter than Earth.

Predict the gravitational force between Mars and the Sun.

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(3 marks)

(c) Determine the acceleration of free fall on a planet 20 times as massive as the Earth and with a radius 10 times larger.

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(2 marks)

(d) Calculate the orbital speed of the Earth around the Sun.

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(3 marks)

2 (a) A satellite orbits the Earth with mass *M* above the equator with a period, *T* equal to 48 hours. The mass of the Earth is 5.972×10^{24} kg.

Derive an equation for the radius, *r* of the satellite's orbit.

(4 marks)

(b) The mean radius of Earth is 6.37×10^{6} m.

Calculate the height of the satellite above the Earth's surface.

(3 marks)

(c) The Hubble Space Telescope is in orbit around the Earth at a height of 490 km above the Earth's surface.

Calculate Hubble's speed.

(3 marks)

(d) Calculate the magnitude of the gravitational field on the Hubble Space Telescope at this height above the Earth's surface.

(2 marks)

3 (a) Europa, a moon of Jupiter, has an orbital period of 85 hours and an orbital radius of 670 900 km.

Outline why Europa moves with uniform circular motion.

(3 marks)

(b) Show that the orbital speed of Europa is 14 km s^{-1}.

(3 marks)

(c) Deduce the mass of Jupiter.

(3 marks)

(d) Ganymede is the largest of Jupiter's Moons. It has an orbital period of 7.15 days and an orbital speed of 10.880 km s^{-1}.

Calculate the orbital radius of Ganymede in terms of billions of km.

(3 marks)

4 (a) Define Newton's universal law of gravitation.

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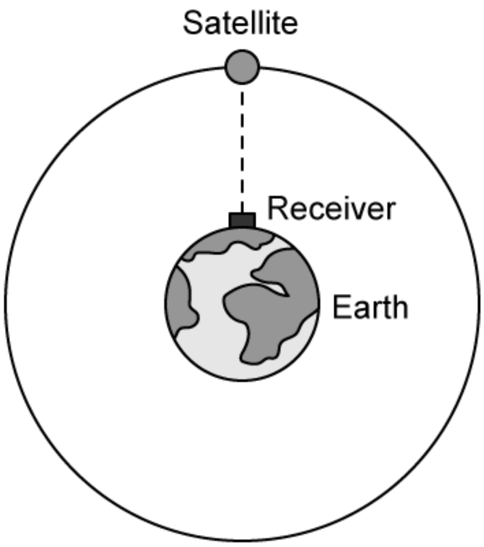
(2 marks)

(b) The diagram shows a satellite orbiting the Earth. The satellite is part of the network of global–positioning satellites (GPS) that transmit radio signals used to locate the position of receivers that are located on the Earth.



When the satellite is directly overhead the microwave signal reaches the receiver 62 ms after leaving the satellite.

Calculate the height of the satellite above the surface of the Earth.

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(2 marks)

(c) Explain why the satellite is accelerating towards the centre of the Earth even though its orbital speed is constant.

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(2 marks)

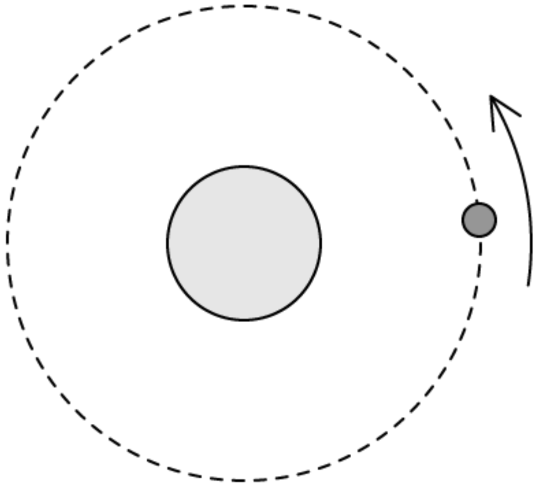
(d) The radius of Earth is 6.4×10^6 m.

Calculate the gravitational field strength of the Earth at the position of the satellite.

Mass of Earth = 6.0×10^{24} kg

(2 marks)

5 (a) A satellite is in a circular orbit around a planet of mass *M*.



Sketch arrows to represent the velocity and acceleration of the satellite.

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(2 marks)

(b) Show that the angular speed, ω is related to the orbital radius r by

$$r = \sqrt[3]{\frac{GM}{\omega^2}}$$

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(2 marks)

(c) Because of friction with the upper atmosphere, the satellite slowly moves into another circular orbit with a smaller radius before.

Suggest the effect of this on the satellites angular speed.

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(2 marks)

(d) Titus and Enceladus are two of Saturn's moons. Data about these moons are given in the table.

Moon	Orbit radius / m	Angular speed / rad s^{-1}
Titan	1.22×10^9	
Enceladus	2.38×10^8	5.31×10^{-5}

Determine the mass of Saturn.

(3 marks)

Hard Questions

1 (a) The gravitational field strength on the moon's surface is 1.63 N kg^{-1}. It has a diameter of 3480 km.

(i) Calculate the mass of the moon

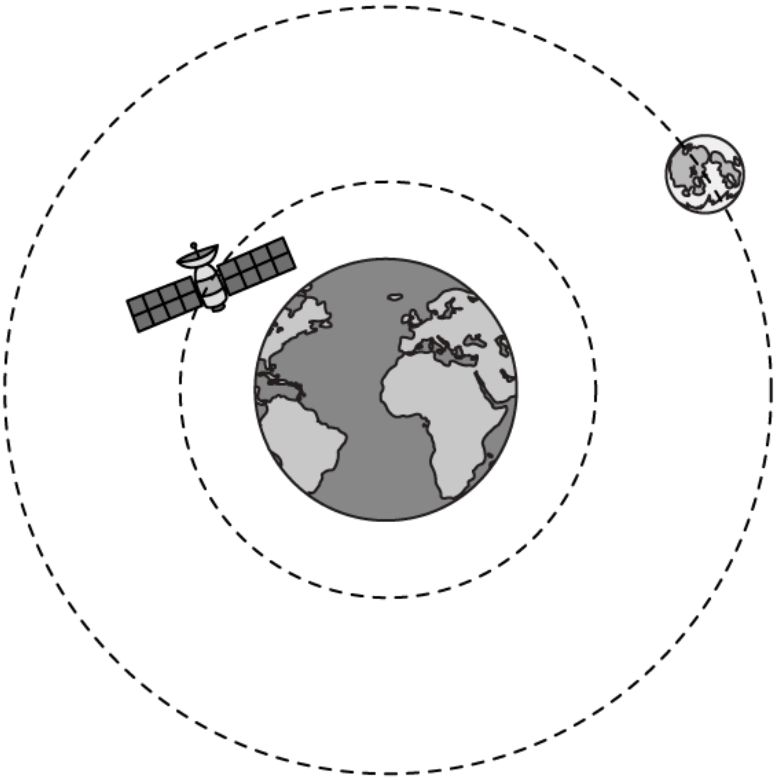
[2]

(ii) State the assumption necessary for part (i)

[1]

(3 marks)

(b) The ISS orbits the Earth at an average distance of 408 km from the surface of the Earth.



The following data are available:

- Average distance between the centre of the Earth and the centre of the Moon = 3.80×10^8 m
- Mass of the Earth = 5.97×10^{24} kg
- Radius of the Earth = 6.37×10^6 m

Calculate the maximum gravitational field strength experienced by the ISS. You may assume that both the Moon and the ISS can be positioned at any point on their orbital path.

(4 marks)

(c) Show that the gravitational field strength g is proportional to the radius of a planet r and its density ρ.

(3 marks)

(d) Two planets X and Y are being compared by a group of astronomers. They have different masses.

Planet X has a density ρ and the gravitational field strength on its surface is g. The density of planet Y is three times that of planet X and the gravitational field strength on its surface is 9 times that of planet X.

Use the equation you derived in part (c) to show that the mass of planet Y is roughly 80 times larger than the mass of planet X.

(4 marks)

2 (a) The gravitational field strength on the surface of a particular moon is 2.5 N kg^{-1}. The moon orbits a planet of similar density, but the diameter of the planet is 50 times greater than the moon.

Calculate the gravitational field strength at the surface of the planet.

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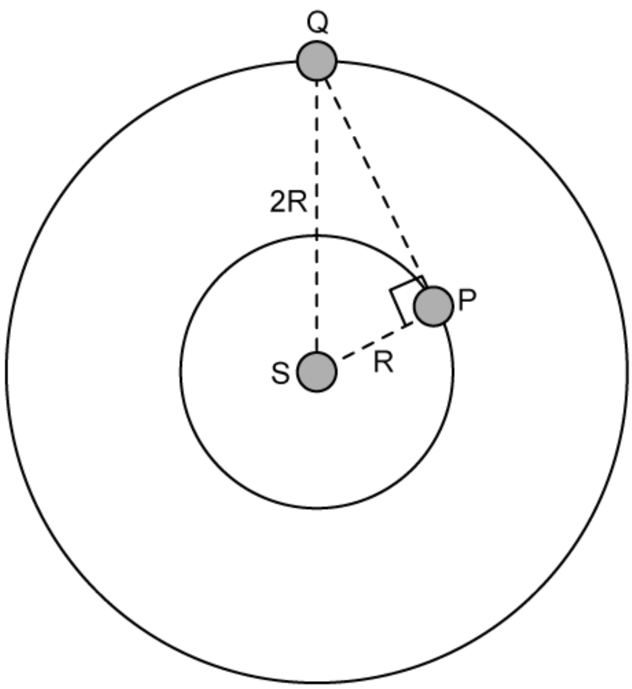
(3 marks)

(b) Two planets P and Q are in concentric circular orbits about a star S.



The radius of P's orbit is *R* and the radius of Q's orbit is 2*R*. The gravitational force between P and Q is *F* when angle SPQ is 90° as shown.

Deduce an equation for the gravitational force between P and Q, in terms of *F*, when they are nearest to each other.

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(3 marks)

(c) Planet P is twice the mass of planet Q.

Sketch the gravitational field lines between the two planets on the image below.

Label the approximate position of the neutral point.

(2 marks)

3 (a) The distance between the Sun and Mercury varies from 4.60×10^{10} m to 6.98×10^{10} m. The gravitational attraction between them is *F* when they are closest together.

Show that the minimum gravitational force between the Sun and Mercury is about 43% of *F*.

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(3 marks)

(b) Mercury has a mass of 3.30×10^{23} kg and a mean diameter of 4880 km. A rock is projected from its surface vertically upwards with a velocity of 6.0 m s^{-1}.

Calculate how long it will take for the rock to return to Mercury's surface.

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(3 marks)

(c) Venus is approximately 5.00×10^{10} m from Mercury and has a mass of 4.87×10^{24} kg. A satellite of mass 1.50×10^{4} kg is momentarily at point P, which is 1.75×10^{10} from Mercury, which itself has a mass of 3.30×10^{23} kg.

Calculate the magnitude of the resultant gravitational force exerted on the satellite when it is momentarily at point P.

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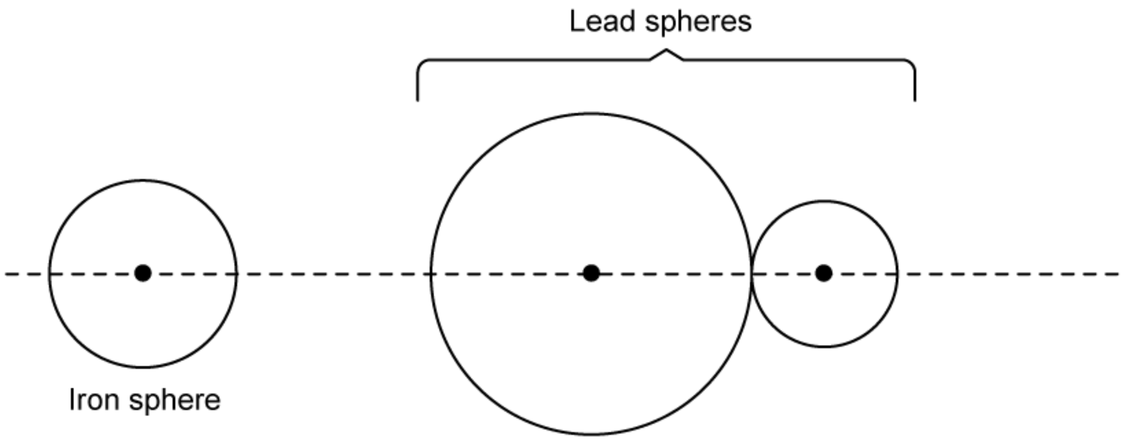
(6 marks)

4 (a) A student has two unequal, uniform lead spheres.

Lead has a density of 11.3×10^3 kg m^{-3}. The larger sphere has a radius of 200 mm and a mass of 170 kg. The smaller sphere has a radius of 55 mm.

The surfaces of two lead spheres are in contact with each other, and a third, iron sphere of mass 20 kg and radius 70 mm is positioned such that the centre of mass of all three spheres lie on the same straight line.



Calculate the distance between the surface of the iron sphere and the surface of the larger lead sphere which would result in no gravitational force being exerted on the larger sphere.

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(3 marks)

(b) Calculate the resultant gravitational field strength on the surface of the iron sphere.

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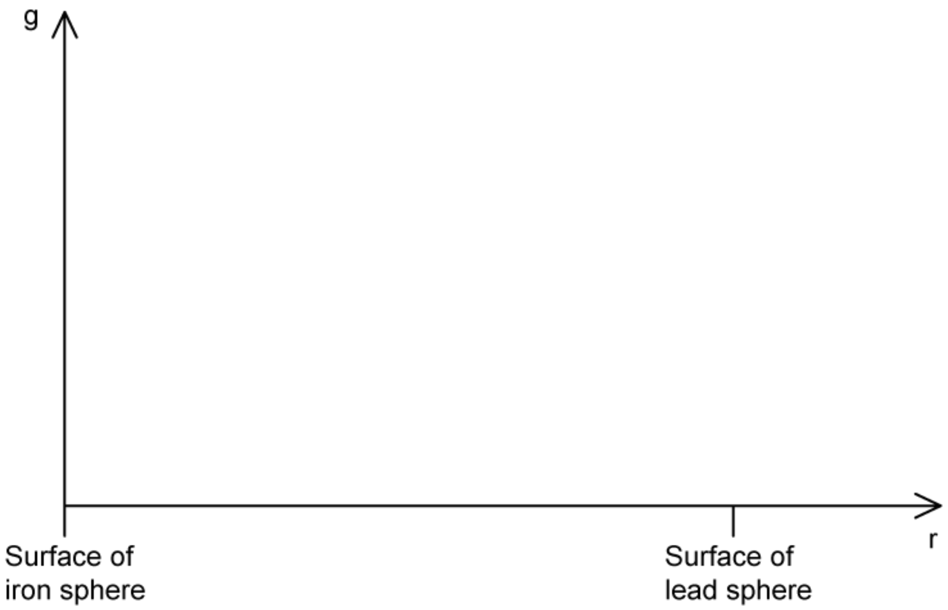
(3 marks)

(c) The smaller lead sphere is removed. The separation distance between the surface of the iron sphere and the large lead sphere is *r*.

Sketch a graph on the axes provided showing the variation of gravitational field strength *g* between the surface of the iron sphere and the surface of the lead sphere.



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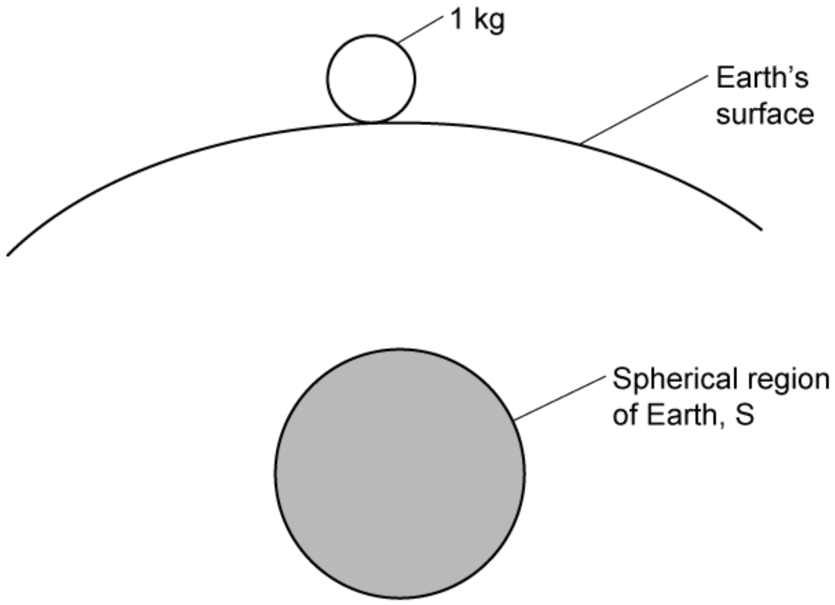
(3 marks)

5 (a) A kilogram mass rests on the surface of the Earth. A spherical region S, whose centre of mass is underneath the Earth's surface at a distance of 3.5 km, has a radius of 2 km. The density of rock in this region is 2500 kg m^{-3}.



Determine the size of the force exerted on the kilogram mass by the matter enclosed in S, justifying any approximations.

(3 marks)

(b) If the region S consisted of oil of density 900 kg m^{-3} instead of rock, the force recorded on the kilogram mass would reduce by approximately 2.9×10^{-4} N.

(i) Suggest how gravity meters may be used in oil prospecting.

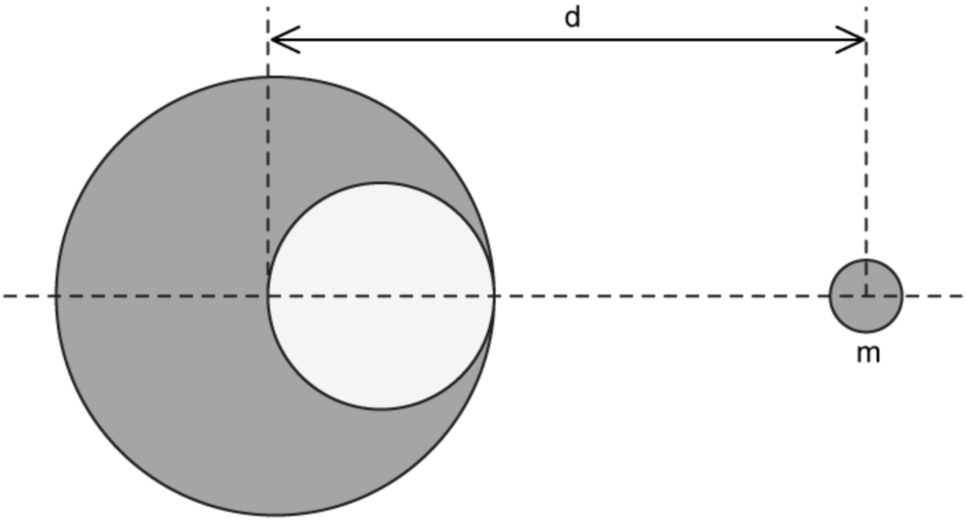
[1]

(ii) Determine the uncertainty within which the acceleration of free fall needs to be measured if the meters are to detect such a quantity of oil.

[2]

(3 marks)

(c) A spherical hollow is made in a lead sphere of radius R, such that its surface touches the outside surface of the lead sphere on one side and passes through its centre on the opposite side. The mass of the sphere before it was made hollow is M.



Show that the magnitude of the force F exerted by the spherical hollow on a small mass m, placed at a distance d from its centre, is given by:

$$F = \frac{GMm}{d^2}\left(1 - \frac{1}{8}\left(\frac{2d}{2d - R}\right)^2\right)$$

[4]

(4 marks)

6 (a) Scientists want to put a satellite in orbit around planet Venus.

Justify how Newton's law of gravitation can be applied to a satellite orbiting Venus, when neither the satellite, nor the planet are point masses.

(2 marks)

(b) The satellite's orbital time, T, and its orbital radius, R, are linked by the equation:

$$T^2 = kR^3$$

Venus has a mass of 4.9×10^{24} kg.

Determine the value of the constant k, and give the units in SI base units.

(6 marks)

(c) One day on Venus is equal to 116 Earth days and 18 Earth hours.

Determine the orbital speed of the satellite in m s^{-1}.

(2 marks)